Turk J Phys Med Rehab 2023;69(4):391-399
DOI: 10.5606/tftrd.2023.12988
Available online at www.turkishjournalpmr.com

Invited Review

Lower limb prosthetic prescription

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Received: April 26, 2023 **Accepted:** May 05, 2023 **Published online:** May 31, 2023

ABSTRACT

Lower limb amputations are the most common level of amputation. Mobilization of patients with lower limb amputations is an important rehabilitation goal. It is critical to prescribe the most appropriate prosthesis for the patient to achieve the rehabilitation goal in lower extremity amputations. Appropriate prosthesis prescription in lower extremity amputations is based on the selection of the correct prosthetic parts. The choice of prosthesis should be based on the patient's activity level and potential. The prosthesis decision should be made by a team, particularly with the participation of the patient.

Keywords: Amputation, lower limb, prosthesis.

Amputation rehabilitation is a long rehabilitation process that includes many stages such as preoperative period, early postoperative period, pre-prosthetic period, prosthetic prescription period, prosthetic training, community integration, and vocational rehabilitation. One of the main stages is to prescribe the appropriate prosthesis for the patient.

Lower limb amputations are the most common level of amputation.[1] Improving independence, regaining functional mobility, and improving quality of life after lower extremity amputations are among the goals of amputation rehabilitation. To achieve these goals as soon as possible following amputation, the patient should be prescribed the appropriate prosthesis and a rehabilitation program should be organized.[2]

Lower extremity prosthesis prescription should be planned by evaluating the patient considering several factors such as stump length and shape, skin condition, muscle strength, upper extremity functions, body weight, occupation, hobbies, activities of daily living, age, cognitive status, allergy, comorbidity, prosthesis experience, and activity level.

The prosthesis decision should be made by a team led by a physical therapy and rehabilitation specialist with the participation of orthotic prosthesis technician, physiotherapist, social worker, psychologist and, most importantly, the patient. Amputees desire to lead an independent lifestyle and actively participate in daily life tasks. To achieve these goals, patients need to be able to stand and walk safely with their prosthesis in different situations and on different surfaces. They also desire less cognitive effort while using the prosthesis so that they can perform different activities at the same time. The needs of amputees are quite different and depend on factors such as activity level, health status, age and sex.[3] Therefore, patient participation is of utmost importance while deciding on a prosthesis.

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Cite this article as:
Kılınç Kamacı G, Aydemir K. Lower limb prosthetic prescription. Turk J Phys Med Rehab 2023;69(4):391-399. doi: 10.5606/tftrd.2023.12988.

In lower extremity prosthesis prescription, it is important to determine the activity level of the patient and to choose the prosthesis appropriate for the activity level. The activity level of patients with lower limb amputation is determined by the Functional Classification Levels.[4] In many countries, including Türkiye, the Functional Classification Levels are used in the selection and payment of prosthesis and prosthetic materials for patients (Table 1).

The Amputee Mobility Predictor (AMP) is a reliable and valid scale to assess functional ambulation with and without prosthesis in lower limb amputees.[5] It consists of 21 items assessing activities such as sitting balance, getting up from a chair, standing balance, walking, going up and down stairs. The AMP is one of the scales used to determine K activity level.[4,5]

In lower extremity prosthesis prescription, it is essential to decide on the right prosthetic parts suitable for the patient.

BELOW-KNEE PROSTHESIS

It consists of suspension, socket, liner, pylon, and foot parts (Figure 1).

1. Suspension: The suspension is the part that keeps the prosthesis on the stump. It prevents the prosthesis from leaving the stump during the swing phase of the gait. Good suspension reduces movement between the stump and socket, improves proprioception and minimizes the energy requirement for walking.[6]

a. ***Classical suspension systems:*** It may be preferred in amputees with lower activity levels.[6]

- Supracondylar and suprapatellar cuff/strap
- Supracondylar pelite liner with compressible or removable wall
- Auxiliary suspension with sleeve
- Suction with or without liner
- Thigh corset and side joints

b. ***Pin-lock systems:*** Suspension is achieved by inserting the pin distal to the liner into the locking mechanism distal to the socket. The pin-lock system has the advantage of being easy to wear. Rotation of the stump may occur during heel strike in the stance phase of gait. Pin-lock systems are practical and suitable in the absence of distal stump pain.[6]

c. ***Vacuum systems:*** It provides an effective suspension by allowing the air between the socket and the liner to escape with the help of a valve or pump. Vacuum suspension may be preferred for active users, as it increases proprioception.[6]

Passive vacuum system: There is a one-way valve that creates the vacuum between the liner and the socket. The passive vacuum system is preferred for stumps that are not short. Passive vacuum system with prosthetic knee sleeve is used with polyurethane or gel liner.

TABLE 1
Functional classification levels

K level	Functional level	Activity level
K0	No potential for ambulation or transfer	No potential or ability to ambulate or transfer with or without assistance, and a prosthesis does not improve quality of life or mobility.
K1	Potential in-home ambulation, including transfer	Potential or ability to use a prosthesis on flat surfaces with a fixed number of steps. In-home ambulation with or without restrictions is typical.
K2	Potentially limited community ambulation	Has low potential or ability to ambulate across environmental barriers, e.g., sidewalks, stairs or uneven surfaces. Limited community ambulation is typical.
K3	Variable step counts (cadence), including community ambulation, therapeutic exercise or work	There is potential or ability to ambulate at variable step counts. Ambulation in the community is typical, most can overcome environmental barriers, have a job, perform therapeutic or exercise activities beyond simple walking.
K4	High activity user above normal ambulation skills	Beyond basic ambulation skills, there is potential or ability to ambulate at high levels of impact, stress or energy. Typical for a child, active adult or athlete needing a prosthesis

Figure 1. Below-knee prosthesis.

Passive vacuum system without knee sleeve is preferred, if there is a stump length of at least 15 cm and is used with a membrane liner.

Active vacuum system: Suspension is provided by a pump between the liner and the socket through which the air is expelled. Active vacuum system with prosthetic knee sleeve is preferred for short stumps to prevent air intake for suspension. Active vacuum system with knee sleeve is used with polyurethane or gel liner. It is not preferred in patients who cannot transfer weight to the tip of the stump due to neuroma, dialysis patients and those with impaired cognitive status.

2. Socket: It is the part that fits inside the stump and transfers the ground reaction forces to the stump during the stance phase of walking. The socket should stabilize the stump in the sagittal and coronal planes, provide support for body weight, ensure proper functioning of the existing muscles, and offer a harmony of function and comfort both statically and dynamically.[7] The socket must be custom-made for each amputee.

- ***a. Patellar tendon bearing (PTB):*** The patellar tendon area carries most of the body weight. It is not used on very short stumps. It is contraindicated in flexion contractures of the knee joint above 45°.
- ***b. Patellar tendon bearing-supracondylar (PTB-SC):*** It provides suspension from the medial epicondyle. Knee extension control is eliminated. It can be preferred in patients who demand to perform the squat movement easily.
- ***c. Patellar tendon bearing-supracondylar/suprapatellar (PTB-SPSC):*** It is preferred for short stumps. It provides suspension from the patella. It increases the anteroposterior, mediolateral stability of the knee joint. It should not be preferred for individuals who do squatting activity excessively.
- ***d. Total surface bearing (TSB):*** The TSB ensures that the load is evenly distributed on the socket wall and the weight can be carried over a larger surface. Good contact between the socket and the stump improves the fit and has a positive effect on the suspension. It increases circulation in the stump and prevents wound formation. Proprioceptive sensation increases due to even load distribution.[7]

3. Liner: Liner is the part used between the stump and the socket, which acts as a shock absorber.[6] The contact of the stump to the socket can use a hard or soft interface. Soft liner options are suitable for many amputees. Soft liner materials include pelite gel, polyurethane or silicone liners. The disadvantages of soft inserts are heat retention, susceptibility to wear and tear, additional bulk and a tendency to absorb odors. The choice of the most suitable interface system depends on the individual needs and characteristics of the patient.[8]

4. Pylon: It is the part that connects the socket and foot parts.

5. Prosthetic feet: A prosthetic foot is expected to provide a successful and near-normal energy expenditure, to absorb the shock caused by ground reaction at the beginning of the stepping phase, to provide a stable support surface during standing and to provide a cosmetic appearance. Factors affecting the choice of prosthetic foot are the patient's age, weight, and living environment, level of amputation, stump length, occupation and activity level. There is a wide range of prosthetic feet. These feet are made of various materials. Each foot has own characteristics and certain advantages and disadvantages.[8]

a. ***SACH (solid ankle cushioned heel):*** Its advantages include lightness, durability due to the absence of moving parts, resistance to dust and moisture, and ease of repair (Figure 2a). It can be used for transtibial amputations to provide a basis for standing and walking.[9] It is suitable for classical and modular prostheses and for activity level K1.

b. ***Single-axis foot:*** It allows dorsal and plantar flexion around the transverse axis (Figure 2b). Less movement of the prosthetic ankle joint compared to the normal ankle reduces ramp adaptation. This foot is suitable for activity levels K1 and K2. Maintenance of moving parts and difficulty of repair are the main disadvantages. Single axis foot offers an advantage in terms of sagittal kinematics.[10]

c. ***Multi-axial foot:*** It allows inversion-eversion, plantar flexion, dorsiflexion movements of the ankle. Adding multi-axial function to a foot, seems to improve involved-side kinetics.[10] This foot is suitable for uneven ground and K2 activity level. High ankle motion decreases stability. Disadvantages include its weight and difficulty of repair.

d. ***Dynamic foot:*** It facilitates the rocker movement in the foot during walking and absorbs shock. It is light and flexible. Its most important advantage is that it can stretch particularly in the foot axis and metatarsophalangeal joints. Suitable for K2 and above activity levels.

e. ***Carbon foot:*** They are often preferred, as they are durable and lightweight (Figure 2e). The

Figure 2. **(a)** SACH (Solid Ankle Cushioned Heel). **(b)** Single-axis foot. **(c)** Hydraulic foot. **(d)** Microprocessor controlled foot. **(e)** Carbon foot.

carbon foot contributes to the push off with the energy it stores in the stance phase and supports the gait.[9] There is a carbon foot option for all activity levels.

Carbon foot (K2): This foot is made of a flexible, lightweight, plantar flexed, carbon composite.

Carbon foot (K3): This foot is made of a flexible, lightweight carbon composite that can perform inversion, eversion, plantar flexion and torsion.

Carbon foot (K4): This foot is made of carbon composite that is flexible, lightweight, capable of inversion, eversion, plantar flexion, torsion and vertical loading.

f. ***Hydraulic foot:*** It allows 20 degrees of dorsiflexion and plantar flexion angle at the ankle. It provides a more natural gait and an advantage in ascending and descending ramps. Its disadvantages include being heavy and needing more frequent maintenance (Figure 2c).

g. ***Microprocessor controlled foot:*** It partially reduces energy consumption and provides a more comfortable walk on uneven surfaces. By varying the heel height, it offers the option of using shoes of different heights. Its heavy weight and high cost are among its disadvantages (Figure 2d).

PARTIAL FOOT PROSTHESES

In partial foot amputations, the weight is carried by the heel and surrounding adipose tissue. This area is delicate and therefore the load needs to be distributed over a wide area to ensure stump socket fit. Therefore, partial foot prostheses should provide adequate support to the ankle and heel area and should be lightweight and durable.[8]

1. **Chopart prosthesis:** Since the calcaneus is preserved, there is no length difference in the two extremities. The patient can walk without prosthesis. The most important point in Chopart amputations is the difficulty in performing the pushing phase. By providing the pushing phase with the prosthesis, fatigue in patients can be prevented. Chopart prosthesis produced with lamination technique is available (Figure 3). Another Chopart prosthesis application is the prostheses produced with silicone technique. The disadvantages of silicone prostheses are that they are heavy and can be worn out early.

Figure 3. Chopart prosthesis.

Figure 4. Above-knee prosthesis.

2. **Syme prosthesis:** Syme prosthesis is expected to transmit forces between the stump and the socket through the socket, to be light and durable, to adequately assume foot and ankle function, to provide shock absorption, and to provide a cosmetically near-normal appearance.

ABOVE-KNEE AND KNEE DISARTICULATION PROSTHESES

These prostheses consist of a knee joint, suspension, socket, liner, tube, and foot parts (Figure 4). The suspension, socket, liner, tube, and foot parts are similar to below-knee amputations.

Knee joint

Selection of the most appropriate knee joint for the patient and a good rehabilitation program at above-knee and knee disarticulation levels are very important for participation in social and professional life. The knee joint should provide maximum safety during walking and support activities of daily living as much as possible. Knee joints are classified according to their axis of motion and working mechanisms (Table 2).

1. Knee joints according to axis of motion

a. ***Monocentric knee joints:*** Only flexion-extension movement around the transverse axis occurs in this joint. They are light joints and easy to repair. It may be preferred for those who need a small and light knee joint. It is not preferred in patients with a long stump and who rub the foot on the ground during the swing phase.

b. ***Polycentric knee joints:*** Polycentric knee joints produce a moving center of rotation as in the human knee. Knee flexion is more controlled and stability is better. Therefore, it can be preferred in short above-knee amputees and bilateral above-knee amputees. Since it is similar to human anatomy, it can be preferred for long above-knee and knee disarticulation levels, such as in those who have a large difference in length between the knees while sitting.[8]

2. Knee joints according to the working mechanism

a. ***Mechanical knee joints:***

Manuel locking knee joints: In these joints, when the patient lifts the lock part up, the lock is released and the knee joint can move. When the knee is brought into extension, the lock lever automatically descends and the joint is locked. It can be preferred in patients with weak muscle strength and poor coordination. The patient can walk with or without a lock. It can lock on uneven ground and unlock on flat ground. It should not be preferred in patients with cognitive impairment.

Constant friction knee joints: Friction is constant during the swing phase of walking. It is a joint suitable for walking at constant speed. It cannot adapt to changes in walking speed. It can be preferred for those who demand to adjust the swing phase control setting themselves and need a light and durable joint.

Weight locking knee joints: In these joints, the friction mechanism is activated with the application of weight in the stance phase and flexion is prevented in the knee joint.

TABLE 2
Classification of knee joints

According to the axis of motion	According to the working mechanism
- Monocentric - Polycentric	- Mechanical • Manuel locking • Constant friction • Locking with weight bearing - Pneumatic • Swing phase pneumatic, stance phase mechanical controlled - Hydraulic • Swing phase hydraulic, stance phase mechanical controlled • Both swing and stance phase hydraulic controlled - Microprocessor controlled

It may be preferred for those with short stump length and weak hip muscle strength. It is not suitable for those with high activity levels.

b. ***Pneumatic controlled knee joints:*** These joints provide a natural gait with pneumatic control of the swing phase. It is lighter and cheaper than hydraulic and microprocessor joints but less cadence compatible. It can be preferred for those exposed to extreme heat and cold. Not suitable for overweight patients. Suitable for those with activity levels K2-K3.

c. ***Hydraulic controlled knee joints:*** These joints provide both swing and stance phase hydraulic control. Speed changes are easily realized thanks to the resistance changes during the swing phase. These joints provide a high level of safety on stairs, uneven surfaces and ramps. They are suitable for K3-K4 activity level patients. Knees with hydraulic or pneumatic swing phase control allow greater walking comfort, speed and symmetry. Therefore, they are recommended for active amputees.[11]

d. ***Microprocessor controlled knee joints:*** They are the knee joints with an integrated processor or computer that can analyze data. Through sensors, joint angles, step speed, and weight transferred during walking are analyzed to determine the movement for the safest near-normal gait. Using sensors that detect every moment of walking, unwanted movements of the knee joint are restricted and some movements that may be difficult are facilitated. Both swing and stance phases can be microprocessor controlled or only one of the phases can be microprocessor controlled. It is safer to walk on ramps, stairs and uneven surfaces. Suitable for individuals with moderate-to-high activity levels. It can be preferred at K3, K4 activity levels.

Microprocessor-controlled knee prostheses differ from each other in terms of weight/height, sensor and processor frequency, load carrying capacity, the mechanism by which phase control is provided (hydraulic, pneumatic, magnetic), battery properties, water resistance, backward walking, stair climbing and running.[12,13]

Microprocessor-controlled knees are shown to reduce stumbling and falls. They also improve confidence in walking, mobility, satisfaction, and quality of life. Microprocessor knees are shown to increase walking speed, walking speed on uneven terrain and metabolic efficiency during walking. In addition to all these advantages, microprocessor-controlled knees have higher costs.[11]

Suspension

In above-knee amputees, passive vacuum systems are preferred in most patients, as there is sufficient soft tissue around the stump to assist suspension. There is no clinical evidence to indicate which suspension system is effective as a standard system for all transfemoral amputations. Suspension and socket systems in transfemoral amputees should be decided by evaluating the etiology of amputation, the functional status of the amputee, the clinician's experience and the patient's preference.[7]

HIP DISARTICULATION PROSTHESES

Increased energy consumption is seen during ambulation after hip disarticulation. Gait tempo decreases and is constant. Socket fit and correct selection of prosthetic parts are critical. In hip disarticulation, the load is carried from the ischial tuberosity. Since the entire pelvis is taken into the socket, scar tissues and sensitive areas should be protected.

Figure 5. **(a)** Uni-axial hip disarticulation prosthesis. **(b)** Multi-axial hip disarticulation prosthesis.

There are uni-axial and multi-axial hip joints. The uni-axial hip has been the most commonly used type of hip joints (Figure 5a). The multi-axial hip joint provides flexion and extension movement, as well as some rotation (Figure 5b). The use of uni-axial or multi-axial hip joints is determined according to the functional status of the patients. The use of a multi-axial hip joint combined with microprocessor knees is usually recommended for individuals with hip disarticulation level amputation who have a strong potential for community-level prosthetic ambulation.[8]

There are several challenges with prosthesis fit and use at proximal amputation levels. Due to the absence of a stump at these amputation levels, socket fit, prosthesis suspension and alignment are also important considerations.

Uni-axial feet are recommended for those who use the prosthesis on flat surfaces. For those with more community ambulation potential, multi-axial or dynamic response feet may be preferred.[8]

PEDIATRIC LOWER EXTREMITY PROSTHESIS PRESCRIBING

The most important difference of prosthesis prescription in pediatric patients compared to adult patients is that it should be made considering the developmental stages of the child. As children grow faster and are more mobile, it may be necessary to change prosthesis or prosthesis parts frequently. According to the Turkish Social Security System, prosthesis replacement can be performed once a year, if it is stated in the report that the child's growth continues.

Classical or modular lower extremity prostheses may be preferred in pediatric patients. The possibility of repair and modification is higher in modular prostheses compared to classical prostheses. Pediatric patients can continue with classical or modular prostheses until the age of 12-15.

In this patient group, prostheses with a soft socket may be preferred first due to possible changes in stump volume. The light weight of the soft socket is also an advantage. Soft socket may be preferred at knee disarticulation levels. To use the active vacuum system, the child must weigh at least 45 to 50 kg.

Prosthetic knee joint should be applied when pediatric patients develop cognitively and begin to obey verbal commands. Therefore, knee joint should not be given in the first three years of age. In young children, monocentric joints may be preferred due to their light weight. There are different options such as mechanical, pneumatic, hydraulic in pediatric knee prosthetic joints. Hydraulic knee joints can be preferred in children over six years of age. Mechanical hip and knee joints are selected at the hip disarticulation and hemipelvectomy levels.

Dynamic or SACH feet can be preferred because of their light weight. Carbon foot is preferable for children older than six years. In children younger than 18 to 24 months, ortho-prosthesis may be prescribed, as there is no appropriate foot preference. The appropriate foot for the patient is made during prosthesis construction.

In conclusion, to achieve the goal in amputation rehabilitation, it is of utmost importance to choose prosthesis suitable for the patient's age, level of amputation, and functional level. The patient's activities of daily living, expectations and, particularly, activity level should be taken into consideration. Correct prosthesis prescription can be made by determining the right prosthesis parts.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept, design, literature review, writing the article: G.K.K.; Idea/concept, design, literature review, control/supervision: K.A.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

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